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AN INTEGRATED ASSESSMENT OF WATER MARKETS: AUSTRALIA, CHILE, CHINA, SOUTH AFRICA AND THE USA

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An Integrated Assessment of Water Markets: Australia, Chile, China, South Africa and the USA

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Abstract

The paper provides an integrated framework to assess water markets in terms of their institutional underpinnings and the three 'pillars' of integrated water resource management: economic efficiency, equity and environmental sustainability. This framework can be used: (1) to benchmark different water markets; (2) to track performance over time; and (3) to identify ways in which water markets might be adjusted by informed policy makers to achieve desired goals. The framework is used to identify strengths and limitations of water markets in: (1) Australia's Murray-Darling Basin; (2) Chile (in particular the Limarí Valley); (3) China (in particular, the North); (4) South Africa; and (5) the western United States. It identifies what water markets are currently able to contribute to integrated water resource management, what criteria underpin these markets, and which components of their performance may require further development.

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Introduction

Many parts of the world's arid and semi-arid regions face the dilemmas of reduced water supplies (Ludwig and Moench 2009) and an increasing demand for water resources due to population and income growth (Falkenmark 1999). In water scarce and low-income countries, especially those with high population growth rates, the effects on the livelihoods of the poor will be dire without comprehensive efforts to address water scarcity. In rich and dry regions, such as Australia or in the US West, the challenge will be to balance competing demands such as between irrigated agriculture and the environment (Grafton et al 2010).

To address these global water challenges, there is a need for effective institutional arrangements and allocation mechanisms among competing users to mitigate and manage water scarcity. Our contribution is to develop, for the first time, a comprehensive and integrated framework to benchmark water markets, one of the most important allocation mechanisms. The framework is used to identify strengths and limitations in five water markets: Australia's Murray-Darling Basin, Chile (in particular the Limarí Valley), China (in particular, the North), South Africa, and the western United States. All these locations are semi-arid and face, to a greater or lesser extent, an expectation of reduced water availability associated with climate change. Two are in rich countries (Australia and the United States), two are in low to middle-income countries (Chile and South Africa), and one is in a poor, but rapidly developing country (China).

To provide the comparisons across different water markets we use both a qualitative and quantitative framework that provides an assessment over 26 criteria in four key categories: institutional underpinnings (eight criteria), economic efficiency (eight criteria), equity (five criteria) and environmental sustainability (five criteria). The framework allows us to identify what water markets are currently able to contribute to integrated water resource management, what criteria underpin these markets, and which components of their performance may require further development.

In the following section we describe the integrated framework and provide an overview of the five water markets. Sections three, four, five and six separately evaluate the five water markets, respectively, in terms of their institutional underpinnings, economic efficiency, equity, and environmental sustainability. In section seven we draw together key and general insights from the integrated assessment.

An Integrated Water Markets Framework

Several indicators of water scarcity, water withdrawals, water poverty or 'peak' water have been developed (Palaniappan and Gleick 2009; Postel, Daily and Ehrlich 1996; Shiklomanov 2003; Sullivan 2002). Most of these measures are based on physical quantities of water and are not indicators of the quality of water institutions. A notable exception is a Water Institutions Health Index (WIHI) developed by Dinar and Saleth (2005) and Saleth and Dinar (2004) that uses 16 variables of institutional quality in three broad categories: law-related, policy-related, and organization or administration-related variables. While the WIHI is useful for broad comparisons it was not designed to be an assessment of water markets and, as Dinar and Saleth observe, generates some perverse rankings.[2]

Previous reviews of water markets include Easter, Rosegrant and Dinar (1998; 1999), Howe, Schurmeier and Shaw (1986), Rosegrant and Binswanger (1994), among others. These studies focus on the benefits of water markets and provide guidance as to how they may be improved, typically from an economic efficiency perspective. Our goal is more modest, namely, to show how water markets can, and do, function in very different legal and institutional frameworks and what this implies in terms of efficiency, equity and sustainability. We do not provide specific advice about how to 'improve' water markets and neither do we discuss best practices in terms of water institutions (Saleth and Dinar

[2] The WIHI has only one variable directly related to water markets. This variable evaluates water rights and varies from 0 to 7, where 0 indicates no water rights, 1 unclear/unauthorized/scattered rights, 2 common/state rights, 3 multiple rights, 4 riparian system, 5 appropriative systems, 6 proportional sharing system and 7 indicates the existence of water licenses/permits. It is not clear why a riparian system should receive a higher rank than multiple rights or why appropriative rights are necessarily superior to riparian rights. The WIHI also suffers from perverse overall rankings with Myanmar ranking higher than Australia.

2000). Instead, we develop a comprehensive and integrated framework to generate an ordinal rank of the institutional underpinnings of water markets and their performance in terms of integrated water resource management.

Our approach is 'institutional' (Livingston 1993) because it recognizes that objectives, capacities and institutional constraints differ such that there cannot be a single set of recommendations universally applicable for all water markets. For example, South Africa's *National Water Act 1998* explicitly places equity considerations as a top priority, putting this goal ahead of economic efficiency in terms of how its water markets have developed (Muller 2009). Consequently, recommendations to improve the economic efficiency of water markets without sufficient regard for their equity implications are unlikely to be fully supported within South Africa.

The integrated water markets framework (IWMF) uses a four-point scale in four categories: institutional underpinnings, economic efficiency, equity, and environmental sustainability. It allows for an understanding of the institutional constraints and challenges of implementing water markets, and explicitly considers the 'three pillars' of integrated water resource management developed at the 1992 Dublin International Conference on Water and Environment: equity, economic efficiency and environmental sustainability (Lenton and Muller 2009).

Many of the criteria we use are qualitative measures that are derived from primary or secondary data, but some economic efficiency criteria are quantitative. The qualitative scores provide four ordinal rankings: the highest (three drops) indicates the criterion is nearly or fully operational; two drops indicates the criterion is mostly satisfied but some further development is required; one drop means the criterion is partly satisfied and substantial development is required, while the lowest ranking (X) specifies that the criterion is not operational or is missing. For some criteria, in some water markets, insufficient data or information is available to provide a ranking. The contribution of the integrated framework is that it can be used: (1) to benchmark different water markets; (2)

to track performance over time; and (3) to identify ways in which water markets might be adjusted by informed policy makers to achieve desired goals.

We apply the integrated framework to five water markets: Australia's Murray-Darling Basin, Chile (in particular the Limarí Valley), China, South Africa, and the western United States. In the case of the US limited, local water markets have existed since the nineteenth century, while in China they are still very much in their infancy. Chilean water rights of the Limarí Valley are, arguably, the most entrenched in terms of legal rights, but this market is small in size compared to water markets in Australia's Murray-Darling Basin that were first established in the early 1980s.

In all countries we use secondary data sources that have been supplemented by data, first-hand knowledge and experience with three of these markets (Australia, South Africa and US). The difference in the ranking across the water markets shows that, depending on the goals of policy makers and underlying institutions, markets can deliver very different outcomes. In all cases, even in the most developed water markets, the framework shows that further development of robust water rights and governance are possible, should policy makers wish to undertake the necessary reforms.

Institutional Underpinnings

The IWMF uses eight criteria to assess the institutional underpinnings of water markets, namely: (1) Recognition of the public interest (legal and practical recognition of multiple interests in water resources and measures to reconcile conflicts); (2) Administrative capacity (sufficient administrative authority, resources and information to manage water resources effectively); (3) Well-developed horizontal linkages (robust and clear institutional relationships at a given level of governance); (4) Well-developed vertical linkages (robust and clear institutional relationships between different levels of governance); (5) Legal/administrative clarity (definitional clarity, particularly in relation to water rights, as well as transparent administrative actions); (6) Conflict resolution mechanisms (appropriate and robust mechanisms for resolving conflict between water users and uses where it arises); (7) Adaptive management of institutions (capacity for institutional adaptation); and (8) Registration/titling (sufficient processes for ensuring accurate and updated registration/titling of water rights). A summary of the comparisons of the five markets in terms of these criteria is provided in Table 1.

Recognition of Public Interest

The public interest includes beneficiaries from water resources other than direct water users. This broad conception of the public interest is most developed in Australia, the Colorado Basin and South Africa. In the case of Australia, water resource plans are obliged to "…establish the intended balance between environmental and consumptive use outcomes, as well as setting out terms and conditions for water access" (National Water Commission 2009a, p. 14). In practice, wider interests are not necessarily put into operation (Connell and Grafton 2008). In the US, western states own water in trust for their citizens. Individuals hold *usufruct* rights to the water, subject to the requirement that the use is beneficial and reasonable and is subject to oversight by the state in monitoring applications and water transfers to ensure that they are consistent with the public interest (Gould, 1995, 94). The notion of 'public interest', however, is sufficiently vague and potentially expansive in justifying state intervention with the effect that uncertainty regarding water rights and markets is increased. The South African approach is similar to Australia with the public interest in water resources defined under its *National Water Act 1998* and the national government held as the custodian of the public interest (Nieuwoudt and Armitage 2004, p. 2). In practice, however, the national government has failed to prevent major pollution problems, such as acid mine drainage (Water Research Commission 2009, pp. 14-17), that generate substantial external costs.

The divergence between theory and practice is most evident in Chile and China. In Chile, the *1981 Water Code* specifies "…water is a natural resource for public use" (Hearne 1998: 142), but there appears to be little supporting regulation in place to protect the public interest (Bauer 2004:, p. 33). China's Constitution provides that water resources are owned by the state on behalf of the people (Speed 2010a, p. 207), and its *2002 Water Law* provides a framework for integrated water resource management and includes sections dealing with planning, conservation and pollution control (Khan and Liu 2008, p. 14). Despite the good intentions, however, Chinese water resource planning is still in a ‘developmental phase’ (Liu and Speed 2010, p. 12) and water plans tend to focus solely on allocation and utilization of basin water resources (Zhou 2006, p. 6).

Administrative Capacity

Unsurprisingly, administrative capacity is most developed in the high–income countries: Australia and the US. In both cases, much of this capacity resides at a state level, but in the case of Australia this capacity is rapidly being developed at a federal level consistent with changes in the legal governance of the Murray-Darling Basin following passage of the *Water Act 2007*. In the US, each state has a regulatory agency to monitor whether water is held, used, and transferred consistent with the notions of beneficial use and the public interest. These agencies vary from the State Engineer in New Mexico and Utah, to the Department of Water Resources in Arizona, and to the Department of Natural Resources and special water courts in Colorado.

In South Africa, capacity in the water sector is much more limited, to the extent that the ability of the state to effectively manage and control water resources remains problematic (Malzbender et al. 2005, p. 2). This is evidenced by the continuing failure to effectively implement catchment management authorities, despite more than a decade of trying. A similar problem exists in China, where there are “serious questions about the state’s capacity to tackle water problems” (Lee 2006, p. 10), and although several river basin commissions have been established they have “no effective tools to monitor and supervise water development and use” (Zhou 2006, p. 4). By contrast, the problem in Chile is not so much one of capacity to implement, but rather inadequate regulatory authority. This is because the government’s water rights agency, Direccion General de Aguas (DGA), “…has very little regulatory authority over private water use”, and “cannot cancel or restrict water rights once they have been granted” (Bauer 2004, p. 33).

Horizontal Linkages

Well-developed linkages across governments and agencies are fundamental to ensuring effective water governance where responsibilities are shared. In Australia, cross-government agreements as part of the Council of Australian Governments (COAG) have formed the basis of water reform since the mid 1990s. A willingness to cooperate and cede authority to the federal government in return for financial benefits has also been critical to the water reform process. The substantial inter-basin transfers within South Africa, and also across borders, have necessitated functioning horizontal cooperation and numerous water agreements have been implemented (Turton, Patrick and Rascher 2008, p. 326).

The US federal government has not had the same degree of action in water reform, where water management is left to the states, as in Australia or South Africa. Consequently, institutional relationships are less than clear, with multiple conflicting, overlapping or sequential jurisdictions within states. For example, proposed water trades may have to be approved initially by the irrigation district board within which the water is currently located; the county where the district is found; the state regulatory body; and potentially, federal agencies, such as the Bureau of Reclamation (BOR), if BOR water is involved. Consequently, agency actions may not be consistent. In Chile, while relationships are transparent at lower levels of governance (e.g. between irrigation organizations), significant problems exist at upper levels, particularly between the DGA and the court system in dealing with water conflicts (Bauer 2004, p. 98-9). China has the most fragmented horizontal linkages of the five countries in this study, which has undermined administrative authority and caused confusion (Lee 2006, p. 10; Liu and Speed 2010, p. 17). In addition to the Ministry of Water Resources, there are eight other bureaus with interests in water policy, known collectively as the 'nine dragons' of Chinese water policy (Lee 2006, p. 10).

Vertical Linkages

Well-developed vertical linkages allow for effective implementation of water policy. Australia, until its *Water Act 2007*, lacked any formal linkages across multi-levels of governance except those between catchment authorities and state governments and agencies. Such processes may be effective at a local, catchment level but have proved ineffective when faced with Basin-wide challenges. The US is also characterized by relatively weak vertical linkages. Interstate compacts, where applicable, divide surface waters among the states; state regulatory agencies rule on water transfers involving changes in the timing, nature, and place of diversion; county regulations may restrict water exports; and local water supply bodies, such as irrigation districts with different decision rules and water rights arrangements among their members may have a separate role in approving water transactions (Thompson 1993).

At a much more restricted spatial scale, Chile appears to have the most developed vertical linkages. The inter-connected nature of the Limarí Valley's water infrastructure means that water supply decisions must be closely coordinated between officials and irrigation organizations (Zegarra 2008, p. 40). The top-down nature of water governance in South Africa since the *National Water Act 1998* has generated many challenges, even though in principle the lines of authority are clearly defined. In reality, however, water planning has been rendered ineffective at a catchment level (Farolfi and Perret 2002, p. 3) until capacity and authority are developed in the (still-planned) catchment management authorities. China also has its difficulties with institutional relationships between different levels of government unclear, with confusion and conflict a frequent result (Zhou 2006, p. 5). Fragmented water management systems have been identified by the World Bank (2002, p. 5) as "…the critical unsolved problem" for China's water resources.

Legal/administrative clarity

Legal clarity over water rights, including what they can be used for and the rules of water trade, is a cornerstone of functioning water markets. In Australia, surface water rights are statutory rights that are separated from land rights. In some circumstances they can be attenuated or even acquired without compensation. Chile has the strongest and most broadly-defined water rights (Bauer 1997, p. 13), although there is confusion about the priority of consumptive (predominantly irrigation) and non-consumptive (hydropower) rights (Brehm and Quiroz 1995, p. 15).

In the US West, water rights are typically based on prior appropriation and diversion (Johnson, Gisser and Werner 1981), with diversions prioritized based on the date of the right. In certain areas, however, water rights are not well defined, while in others over allocation of the available water undermines the assurance of receiving water for junior rights. Water rights are, therefore, not always fully quantified. In addition, rights are conditional upon meeting public interest and beneficial use standards, which can be loosely-defined concepts that depend on administrative judgements.

In the case of South Africa, correcting previous injustices – including through water management –– remains the chief national priority, relegating the trading of water rights between relatively privileged farmers to a low-order priority. Registration, licensing and recognition of existing water uses are also required at a catchment level to provide clarity over use rights before trade can occur. Delays in registration have, in many catchments, prevented water users from being assured of their existing rights and impeded trade. Unclear property rights in China continue to cause significant problems for the management of China's water resources (Speed 2010b, p. 88). There remains a lack of transparency surrounding water allocation decisions (Lee 2006, p. 17; Zhou 2006, p. 6), and the opaque legal status of water allocation has led to inconsistencies and implementation difficulties (Shen and Speed 2010, p. 33).

Conflict Resolution

Conflict resolution mechanisms provide a way to overcome disputes that could compromise the functioning of water markets. In Australia, conflicts over water use and tradeoffs are resolved primarily in the water planning framework at both a basin and catchment level. Provided the planning processes are effective, conflicts can be resolved in timely and effective ways. Where there have been difficult tradeoffs, for example between water allocations to the environment to the detriment of irrigators, the federal government has provided substantial funding, worth some $8 billion, to smooth the transition (Crase and O'Keefe 2009).[3]

[3] We have converted Australian dollars to US dollars at the rate of $A 1.00= US$ 0.90.

The approach to conflicts in both Chile and the US has primarily been one of litigation. In Chile, conflicts that cannot be solved through private bargaining have gone to the court system which, to date, “has not demonstrated the institutional capacity to resolve water conflicts” (Hearne 1998, p. 146). In the US, state regulatory agencies have a review process for water trades to determine whether they meet the no harm requirement and are in the public interest. If opposed, trades can be modified or halted. A source of potential judicial action is the Public Trust Doctrine, a common law notion that emphasizes the public nature of water and other natural resources (Sax, 1970; Brewer and Libecap, 2009). Because there is no compensation for rights holders who lose water under the doctrine, conflicts over water reallocation can be long lasting (Libecap, 2007, 148-51).

In South Africa conflicts are on-going. Until and unless there are effective catchment management authorities that encompass all stakeholders these difficulties are unlikely to be resolved. In China, the *2002 Water Law* contains provisions relating to dispute settlement (Liu and Speed 2010, p. 9). However, shortcomings in the water planning framework have allowed inconsistencies to emerge between regional and local water plans, increasing the potential for conflict in times of water shortage (Liu and Speed 2010, p. 18).

Adaptive Institutions

Australia’s *Water Act 2007* was a radical shift in responsibility of water planning and management and was agreed to by all levels of government and with bi-partisan support. This suggests that, at least at the present time, Australia has the most adaptable institutions of the countries in this study. This adaptability is, undoubtedly, linked to what has been perceived as a national water crisis that has provided a motivation to political leaders to resolve the problems. By contrast, in Chile there have been numerous attempts since 1990 to reform Chilean water law, but these have been blocked by minority parties (Bauer 1997, p. 13; Zegarra 2008, p. 29).

In the US, institutional heterogeneity within and across states provides opportunities for learning and innovation. For instance, many water supply organizations have historically resisted water transfers (Thompson, 1993), but as the potential gain from exchange rises, some irrigation districts have become more responsive (Eden et al. 2008). Additionally, water trading for environmental purposes has been enacted within the Central Valley Project in California (Brewer, Fleishman, Glennon, Ker, and Libecap 2008). Other examples of institutional adaptation include: voluntary settlement agreements in New Mexico, whereby claimants in over-allocated and un-adjudicated systems have agreed to assign water rights outside traditional prior appropriation (Richards 2008); and the unitization of groundwater, where pumpers in the Escalante Valley pool their interests and manage the pumping of the reservoir.[4]

South Africa radically changed its water institutional framework with its *National Water Act 1998* that provides for centralized control of water resources. Since its passage, the focus has been to implement the various reforms rather than embark on further institutional change. China's recent development of river commissions for its seven major basins is illustrative of adaptability, as is the *Water Law 2002* which, on paper, contains many provisions conducive to sound water management. The ability of institutions to adapt in practice, however, has lagged significantly behind the ideals espoused in official laws and regulations, and enforcement/compliance remains debilitating (Liu and Speed 2010, p. 17).

Registration/Title of Water Rights

The registration of water titles is a necessary first step to ensure comprehensive water trading in formal water markets. Currently, Australia has the most complete system of registration of water rights and titles, but further development is required to develop a national and compatible register ─ a stated goal of the federal government. At present, titles are set at a state level and there are substantial differences that impede inter-state water trade (National Water Commission 2009a, p. 120). In the US, there is no single or central water title office. Existing surface water rights have their priority date and allotments of water set, but quantification of water that accrues

[4] See http://aquadoc.typepad.com/waterwired/2010/05/groundwater-unitization-in-utah-todd-jarvis-is prescient.html

to these rights is not quantified in some Basins. In Chile, China and South Africa there are on-going centralized processes to register titles to water rights.

Economic Efficiency

One of the key attributes of water markets is their ability to transfer water from lower to higher value uses. In this section we provide three ways of quantifying the efficiency of water markets: (1) Size of the market (volume of water traded of permanent and temporary water rights as a percentage of total water rights); (2) Estimates of the annual gains ($) from water trade; and (3) Size of storages (that allows for trades over a longer duration and trades upriver). In addition, we present qualitative measures of economic efficiency: (1) Nature of water rights (the extent to which they are unbundled); (2) Quality of title (extent to which rights are recognized in law and in practice); (3) Breadth of market (capacity for water trading between catchments, including upstream trades, as well as inter-sectoral trading); (4) Stability of price formation (predictability of prices given changing water availability); and (5) Availability of market price information (accessibility and reliability of price information). These criteria are summarized in Table 2.

Size of Water Market

Chile's Limarí Valley (Hadjigeorgalis and Lillywhite 2004, p. 9) and Australia's Murray-Darling Basin (National Water Commission 2009b, p. 5) have well developed water markets in terms of the amount traded as a proportion of the entitlements available. The amount traded is some 30% in both locations, including permanent and temporary water rights, which is extraordinarily high. Data is not available across all the US West to make a similar calculation, but the amount of water traded as a proportion of total water use appears to be an order of magnitude smaller. Nevertheless, substantial volumes of water are traded in US water markets, as is demonstrated by the following figures, by state, between 1987 and 2008: Texas (38,700 GL); Arizona (27,500 GL); and California (24,500 GL).[5] These amounts are based on committed volumes where the annual amounts are projected forward for the term of the contract and discounted back at 5% (Brewer, Glennon, Ker, and Libecap 2008, p. 99). In terms of the total

[5] All values in acre-foot have been converted to Gigaliters (GL, one thousand million liters) or Megaliters (ML, one million liters) at the rate 1.0 acre-foot = 1.233482 ML.

value of trades from 1987-2008, the leading states are California ($1.33 billion); Texas ($0.86 billion); Arizona ($0.84 billion); Colorado ($0.82 billion); and Nevada ($0.73 billion).[6] As of 2010, there have been only limited transfers of water rights in South Africa, although this may change after all rights are registered (expected by the end of 2011). Similarly, in China there are only *ad hoc* transfers that may amount to less than 0.1% of the total volumes used (derived from Speed 2010b, p. 85 and Liu and Speed 2010, p. 15).

Gains from Trade

To be able to calculate gains from trade requires data on actual transactions. These data, at best, are only partially available for China and South Africa. Calculations of the gains from trade in Chile indicate that the benefits of water markets are substantial and amount to between 8 and 32 per cent of agricultural contribution to regional GDP (Hadjigeorgalis and Lillywhite 2004, p. 9), or some $22 million annually. Australian water markets are much larger, with the total volume of trade in the Murray-Darling Basin worth over $1.8 billion in 2009 (National Water Commission 2009b) and estimated gains from trade in a dry year around $495 million (Peterson et al. 2004, p. 43). In the USWest, the average annual value of water trading between1987-2008 was about $400 million.[7] Annually, the value of water transactions for all contract types and sectors varies from under $1 million in Montana and Wyoming, the two least urban western states, to near $40 million in Arizona, Colorado, Nevada, and Texas; and over $223 million in California. The high turnover in California is driven by one-year leases within agriculture and a few large multi-year leases from agriculture to urban use.

Nature of Water Rights

In the past 15 years water rights in Australia have, more or less, been separated from land rights. Although some riparian rights (stock and domestic use by farmers) still exist, essentially water

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[6] The values are in $2008 and involve all transactions in the Bren School water transfer dataset across 12 western states from 1987-2008 as interpreted from discussion in the *Water Strategist* where price was included and maintained at http://www.bren.ucsb.edu/news/water_transfers.htm. Multi-year lease and sales cash flows are discounted by 5%. For California six large leases were not included as extreme outliers. $1 billion = $1,000 million.

[7] Calculated from data in the Bren School water transfer dataset and is the sum of the price of transactions across 12 western states from 1987-2008 in 2008 $.

rights can, in principle, be traded across catchments without also acquiring the land where the water rights were originally located (National Water Commission 2009a, pp. 140-2). These water rights include high reliability entitlements where, in most years, holders of these rights would expect to receive their full allocation, and low reliability rights where in dry years there may be zero allocations of water. In addition, the water market includes two types of trade: a permanent market for the water right and its allocation in per perpetuity, and a seasonal market for the actual allocations of water assigned each year to the permanent water right.

Chile has a similar system to Australia that features both permanent and contingent rights where the latter provide allocations when availability is above-average. In the Limarí Valley there are also both permanent (title) and seasonal trade, with the latter typically more prevalent (Zegarra 2008, p. 5; Hadjigeorgalis and Lillywhite 2004, p. 9). In the US western states, surface water rights are based on the prior appropriation doctrine that allows water to be separated from the land and moved via canals and ditches to new locations (Getches 1997, p. 74-189; Kanazawa 1998; Johnson, Gisser and Werner 1981). Appropriative rights with the earliest water claims are the most secure because they have the highest priority claim on water during drought.

Water rights have been unbundled from land in South Africa since the passage *of National Water Act 1998* (Pott et al. 2009, p. 2) and both temporary and permanent water trading have been observed (Nieuwoudt, Gillet and Backeberg 2005, p. 1). In China, despite the *2002 Water Law*, water rights remain poorly defined at either the regional, irrigation district or farmer level (Speed 2010b, p 88). Water remains an 'open access resource' within the Chinese Constitution (Lee 2006, p. 15) and where rights have been established, allocations have generally not been granted at the farmer level (Shen and Speed 2010, p. 32), with land area often used as a proxy to calculate water charges (World Bank 2002, p. 12).

Quality of Title

The most developed/protected title for water rights is in Chile where it is not possible to modify rights without full compensation (Bauer 1997, p. 13). This provides security to existing rights holders, but has created conflicts where existing uses imposes external costs on others. In Australia, water rights are statutory rights that could, in principle, be revoked or modified without compensation. In practice, however, both state governments and the federal government have sought to protect the existing rights holders by purchasing water rights at the market price when seeking to reduce water diversions and increase environmental flows (Connell and Grafton 2008).

Appropriative water rights in the US West are *usufruct rights*, conditional upon varying state regulations for beneficial use, preferred uses, area of origin restrictions, and public interest/public trust doctrine mandates (Getches 1997, p.128-9).[8] Regulatory mandates vary across states and can raise the transaction costs of transfers and lower the value of water rights. For instance, high conveyance losses and risks associated with environmental mandates result in low levels of reliability for surface water transferred through the Sacramento Delta. Consequently, buyers pay a 20-25 per cent premium for water originating south of the Delta (Hollinshead 2008). The ‘use it or lose it’ requirement of appropriative rights has also motivated rights holders to place water into low-valued applications rather than forgo their water rights. In China the quality of title is not well defined nor necessarily protected in the rule of law. In the case of South Africa, water rights are formally recognized and registered by the Department of Water and Environmental Affairs, but as rights are renewable every five years this restricts the security of tenure (Pott et al. 2009, p. 9).

Breadth of Market

The breadth of water markets is defined spatially as well as by trades across competing uses. While Australia has well developed water markets over a very large spatial area within irrigated agriculture, there have been relatively few agricultural-urban trades. This is not because of legal restrictions, but has arisen because state governments that control urban water supplies have eschewed, at least until very recently, the purchase of water from rural areas so as to protect rural livelihoods and communities. As in Australia, the agricultural sector dominates Chile’s water markets (Bauer 2004, p. 88). In the Limarí Valley, there has been limited trade activity by

[8] Wetter western states also allow for some riparian water rights—Washington, Oregon, California, the Dakotas, Nebraska, Kansas, Oklahoma, and Texas

the urban sector because of adequate urban supplies (Easter et al. 1999, p. 14). Importantly, the government has intervened in several inter-sectoral applications for water rather than leave it to markets to resolve (Bauer 1997, p. 11).

In the US West, with the exception of a few locations, the majority of water markets are localized with trading limited to within river basins or sub-basins. Regulatory restrictions and limited conveyance infrastructure are the primary reasons markets have largely emerged at these levels. Nearly every western state has laws which protect basins of origin that make it difficult to export water from one basin to another. Consequently, there is virtually no private water trading across states. The lack of conveyance infrastructure and the high capital costs of moving water also limit the geographic scope of water markets. Most short-term trades are within sector, especially within agriculture. Agriculture-to-urban transactions are dominated by longer term leases and sales, but patterns vary across the states. In South Africa the vast majority of water trading has been within the agricultural sector (Pott et al., pp. 25-6), despite demands for extra water by industry. While inter-sectoral transfers from agriculture to mining would be beneficial for both parties in South Africa it could also “challenge the [equity] objectives of government” (Farolfi and Perret 2002, p. 8) and the priority of providing water to previously disadvantaged individuals (PDIs). Any inter-sectoral water trading must also wait for initial allocation of licenses to be completed (Pott et al. 2009, p. 9). China stands out as the one country where there has been substantial transfer of water from agricultural to industrial and domestic uses. However, this has occurred via water efficiency measures such as lining irrigation channels rather than through a fully operational water market (Speed 2010b, pp. 85-9).

Stability of Price Formation

Smooth price formation, and the avoidance of inexplicable price spikes, is an indicator of a competitive and mature water market. In Australia, water prices are remarkably consistent across catchments in the southern Murray-Darling Basin (National Water Commission 2009b, p. 26-9). Where substantial differences exist it is because of differences in reliability of the water rights or whether they are permanent or seasonal water rights. South Africa’s Lower Orange River, where there is data available (1997-2003), is also characterized by stable price formation (Gillet et al.

2005, p. 10), but with substantial variation in prices associated with changes in water availability (Nieuwoudt and Armitage 2004, p. 3).

In Chile's Limarí Valley, prices of water shares have increased rapidly due to economic development across the mining, industrial and agricultural sectors (Zegarra 2008: 46). Spot prices have, on occasions of low water availability, been very high because irrigators with perennial crops are prepared to pay substantially more than the value of the marginal product if the alternative is the loss of their trees (Zegarra 2008, p.117). In the US West**,** markets are both local and 'thin' such that there is considerable annual fluctuation in prices across time, across jurisdictions, and among sectors. As well as reflecting limited market integration, differences in price across sectors reflect the opportunity cost of water, adjusted for water quality, conveyance, and the priority of the water right. Price differentials can be considerable. For example, median state prices for one-year leases between 1987 and 2008, ranged from \$6.50/ML in Idaho to \$71/ML in Arizona and median sales prices ranged from \$92/ML in Idaho to \$5,344/ML in Colorado.[9] There are also significant price differences in three local markets. Median prices for agriculture-to-urban and agriculture-to-agriculture transactions in the South Platte region of Colorado were \$6,600/ML and \$5,093/ML respectively; in the Truckee Basin of Nevada, \$15,792/ML and \$2,366/ML; and in the Central Valley of California, \$138/ML and \$140/ML.[10] The outlier in terms of price formation is China where water prices are regulated by the government (Liao et al. 2008, p. vi). Consequently, water prices are stable, but they do not reflect changing environmental or economic conditions. Prices for water transfers, for instance between regional governments, are determined through direct negotiation.

Availability of Market Price Information

Market price information is not readily available for all five water markets. The most developed price data is in Australia where state registers are accessible and some water brokers provide information on water prices, sometimes on a commercial basis. In Chile, there is an uneven

[9] The price data are in 2008\$ as discussed in endnote 5 above.
[10] All values are in 2008 \$. Time periods are 2002-8 for Colorado and 2002-9 for Nevada and California. Colorado and Nevada transactions are sales while California transactions are leases (Landry 2010).

spread of pricing information in the market that particularly disadvantages market participants with the least resources and also increases transaction costs (Zegarra 2008: 120). In the US West, markets are generally informal and segmented. Consequently, it is often difficult for buyers and sellers to locate one another. Although brokers are emerging to help create water markets there are no general water rights registries across the US states and accessible price information is restricted to water trade journals. In China, there is no accessible water price information while in South Africa price information is spread from word of mouth (Gillet, Nieuwoudt and Backeberg 2005, p. 10) with no central notice board of pricing. This has led to asymmetries in terms of price information between buyers and sellers (Nieuwoudt and Armitage 2004, p. 3).

Water Storages

In semi-arid climates where rainfall is not evenly spread throughout the year, water storages provide a valuable smoothing function in terms of water availability. The more variable is the climate, the larger are the required storages. In terms of water markets, storages also provide an opportunity for trade over longer periods of time and enable trades upstream provided the transaction takes place before the water is released from upriver storages.

In all five water markets there are substantial water storages that facilitate water trade. The ratios of total capacity of water storages to average water use range from more than two in Australia's Murray-Darling Basin to about three in Chile's Limarí Valley. The ratios vary substantially for the US West, but in Colorado the ratio is 2.3

Equity

Equity can be defined as who gets what water, and when? It is a key component to the successful operation of water markets because perceived unfairness in initial allocations of water can undermine the legitimacy of trades. Inequities may also compromise the overall market if it contributes to water 'poaching' or contravention of water regulations. An assessment of equity is provided below using five criteria: (1) Beneficial use of water extractions; (2) Provision of basic human needs; (3) Limits on market power; (4) Recognition of third-party impacts; and (5) Initial allocation mechanisms that include equity considerations.

Beneficial Use

Beneficial use refers to how the water is used, and whether it is used. In underutilized systems the greater is the beneficial use, the larger are the potential benefits of water diversions. Conversely, in overused systems the imposition of beneficial use for diversions may be inequitable to the extent it limits the rights of users, can be subject to administrative intervention and may contribute to conflicts among users.

Neither Australia nor Chile has explicit provisions for beneficial use although an effectively functioning market provides strong incentives to trade allocations when water is not needed. By contrast, in the US appropriative water rights are conditional upon placing the water in beneficial use. Most western states define beneficial use in terms of the benefit for the appropriator, other persons, or the public with corresponding lists of what is considered beneficial use. Although irrigation was the dominant initial basis for diversion, the set of beneficial uses can be expanded or contracted based on changing public values, judicial interpretations, and constituent group politics. For example, leaving water in stream for habitat has recently been accepted as a beneficial use across US states although its exact definition differs among them (Anderson and Johnson, 1986; Getches, 1997, p.113-4).

South Africa has an explicit consideration of beneficial use that it defines as "…conferring a benefit on the whole population, not just the user" (Pott et al., p. 12). Beneficial use is taken into account when licences are reviewed (Nieuwoudt 2000, p. 2) although there appears to be little transparency around what this means in practice. China, because of its centrally administered nature of water allocation, presumably also incorporates beneficial use in water planning, but again there is no transparency as to what guides actual decisions

Basic Human Needs

Basic human needs can be interpreted in various ways, but is typically defined as meeting the immediate requirements of households in terms of drinking water and sanitation. In both China and South Africa provisions for basic needs are an important part of water planning. In South Africa's case the *National Water Act 1998* aims to ensure adequate water for basic human needs, ecological and development purposes (Farolfi and Perret 2002, p. 3). As a result, the provision of basic water services in townships has been a major priority of the South African government in terms of its water policies. Basic human needs for water appears to be relatively well-provided for in China despite an absence of provisions within water planning (Speed 2010b, p. 214).

In Australia, basic human needs are defined in terms of water supplies for communities that depend on rivers for their water supplies. Such communities have the highest order priority of access. In Chile there is a general deference to the urban water supply (Hearne 1998, p. 154), as in the case of Australia, but water scarcity is such that the provision of basic human needs does not currently compromise existing water markets and allocations. This is also true in the US, but should there be extreme water shortages domestic and municipal uses would be preferred over agricultural, industrial and in-stream uses (Trelease 1955, p. 134).

Limits on Market Power

Controls that limit how many water rights one individual can own or hold may be implemented to address perceived abuses of market power, especially in 'thin' water markets. In the case of Australia, concerns over market power have been primarily directed towards the Federal Government that has become the largest purchaser of water rights in the past two years in its attempt to acquire water rights from willing sellers for the environment. A separate arm of the Australian government is charged with ensuring a competitive water market – including addressing potential issues of market power – and its advice will be incorporated into water market rules that will be implemented in 2011 in the Murray-Darling Basin.

In Chile, speculation and hoarding have been significant problems, especially in non-consumptive rights, although these effects have also flowed through to consumptive rights (Bauer 2004, p. 122-3). The purpose of hoarding, however, seems to be a way for holders of water rights to insure themselves against reductions in water availability rather than to exercise market power. In large part, this stems from the fact that reductions in allowable water use are proportionate across all users when water availability declines. In the US, because water markets are local with few traders and trading options, there are potential problems of bilateral monopoly and bargaining problems such as between the Imperial Irrigation District and the City of San Diego (Haddad 2000; Glennon 2009, pp. 258-9) However, because western water markets are so fragmented there is little likelihood of broad market power emerging. Limited trading in both China and South Africa currently makes the exercise of market power a remote possibility, at least until their water markets develop more fully.

Third-party Impacts

Third-party impacts can arise when water trades impose cost on others not accounted for in the transaction by buyers and sellers. In Australia water markets have been constrained and limits imposed on the quantity of sales so as to protect communities from reduced water diversions. These controls have had a negative effect on water transactions and the efficient functioning of water markets (Productivity Commission 2010). Chile’s *1981 Water Code* does not specifically address third-party effects or environmental impacts. The World Bank considers externalities in Chile’s water sector to be pervasive and likely to “become more important in coming decades” (Briscoe, Salas and Peña 1998, p. 15). Externalities as a result of water trading, however, may not yet be a major problem due to the low volume of trade (Bauer 2004, p. 84).

In the US water trades are regulated by states to meet beneficial use and no harm or no injury requirements when they involve changes in location, timing and nature of use that could affect other rights holders (Getches 1997, p. 161). There can also be restrictions to limit negative pecuniary impacts of trades. Despite these equity concerns, most studies suggest that third-party pecuniary effects are small (Hanak 2003, p. 81; Howitt 1994). Overall, ‘no injury’ requirements can be sufficiently vague so as to add uncertainty and raise regulatory costs. Additionally, states generally require that transfers be for consumed, rather than diverted, water to mitigate third-party effects.

Nieuwoudt (2000, p. 8) reports that the South African *National Water Act 1998* "gives prominence to third party (environment and human) issues", although it is difficult to assess how effective these protections are in practice in the absence of significant levels of water trading. In China, water transfers as a result of water 'savings' through lining of irrigation channels is likely to produce third-party effects which, to date, have not been adequately considered (Speed 2010b, p. 89), including in terms of surface-groundwater linkages and wetlands (Xie 2008, p. 76). Importantly, the third-part effects of large inter-basin transfers from South to the North (Ghassemi and White 2007, pp. 307-316) have not been fully compensated.

Initial Allocation Mechanisms

Initial allocations of water rights can be contentious, especially if prior users of water are excluded or provided with a lower share than they had historically. Such allocations may be viewed as inequitable and can contribute to water conflicts that can jeopardize the efficient functioning of water markets.

The challenge in Australia has been to reallocate water rights from existing users to the environment in ways that are equitable and meet societal goals. To date, this has been accomplished with the purchase by the Federal Government of water rights from willing sellers funded from general tax revenues (Connell and Grafton 2008). In the US, water rights in western states are largely based on the prior appropriation doctrine or 'first possession' (Getches 1997, p.74-189; Kanazawa 1998; Johnson, Gisser and Werner 1981). Appropriative rights are based on timing of claim, measured in terms of water diversion, and held conditional on beneficial use. Senior rights have first claim to water and junior rights holders bear more risk during drought.

Since the passage of its *National Water Act 1998*, South Africa has been undergoing a process of compulsory licensing, following which an 'initial allocation' of water licences will occur (Water Research Commission 2009, p. 9). This process may reallocate water to other purposes, such as to previously disadvantaged individuals, without compensation, as way of correcting past inequities. China's 11th five-year plan (2006-10) requires the development of a national initial allocation system (Sun 2010, p. 1), but no clear interpretation of this requirement has been provided to date. Large inter-basin transfers from the South to the North indicate that past water use does not ensure current access. In Chile's *1981 Water Code* prior users, primarily in agriculture, were allocated consumptive water rights, but also included were non-consumptive rights such as for hydro-electric power generation. Disputes over the priority of water rights (consumptive versus non-consumptive) have led to legal challenges (Bauer 2004, p. 103-111). Allocation of return flows to holders of water rights, as part of the *1981 Water Code*, has also disadvantaged the customary practice of using such flows by downstream users.

Environmental Sustainability

Water markets provide a mechanism for the allocation of water between competing water users and market-based consumptive uses. However, unless there is explicit consideration given to non-market uses or set asides/reserves for the public good, markets may not deliver on broader societal goals.

There are several preconditions for meeting environmental sustainability in water management, including adequate information of environmental needs, delivery of water to meet these needs, and an adaptive process to manage these requirements with changing conditions and circumstances. These preconditions are captured in the criteria presented in Table 4, namely: (1) Adequate scientific data to determine hydrological requirements of water-based environmental resources; (2) Adequate provisions for environmental flows; (3) Adaptive management of environmental needs, including the capacity to monitor the environment; (4) Water quality considerations in water planning and markets; and (5) Complementary catchment and Basin-wide planning and trading.

Adequate Scientific Data

Adequate scientific data is required for effective water resource planning that underpins formal water markets. The best available data are in Australia, the US and South Africa. In the case of Australia, much of this data has been developed in the past decade in response to government programs such as the *Living Murray First Step* (Grafton and Hussey 2007), initiated to increase environmental flows. The data are 'patchy' depending on the catchment and are not always accessible even to academic researchers, but are used by water agencies for planning purposes. In the US, state and federal agencies gather and provide information regarding hydrological data on stream flows, water use, and environmental demands. Environmental requirements are project and river specific and there is no central clearinghouse. South Africa has well developed hydrological models of its major catchments and is developing ‘ecological reserves’ as part of its *National Water Act 1998* that has forced water planners to improve data collection and monitoring. Neither Chile (Brehm and Quiroz 1995) nor China (Shen and Speed 2010, p. 33) has adequate water data for environmental purposes.

Provisions for Environmental Flows

In the US all western states recognize that environmental flows are consistent with beneficial use. Quasi-government agencies and private organizations, such as Oregon Water Trust, engage in water leasing or rights acquisition for in-stream flow maintenance (Neuman 2004; Scarborough 2010). However, there is considerable debate about how much water is needed to achieve specific environmental objectives. Cost-benefit analysis is not expressly required under the *Endangered Species Act 1973* or the *Clean Water Acts* of 1972, 1977, or 1987 so that a weighing of opportunity costs generally does not take place in determining environmental flows. Absent these data as well as scientific consensus, there are debates as to whether there is sufficient water or too much water devoted to maintaining flows.

In Australia, Chile and South Africa there is federal legislation mandating provision of water for environmental and public good purposes. In the case of Australia’s Murray-Darling Basin this will be implemented via a Basin-wide plan that will determine sustainable diversion limits for each catchment beginning 2011. At present, water is provided for the environment through water resource planning processes and also through the purchase of water rights by governments from willing sellers. South Africa is also developing ecological reserves of water for public good purposes that include basic human needs as well as for the environment (Farolfi and Perret 2002, p. 3), although progress to date has been slow (Pollard, Toit and Skukuza 2009, p. 2). In China, “…water is generally not allocated to the environment in any meaningful way” (Shen and Speed

2010, p. 33), however, China is in the process of amending water basin plans to account for environmental flows in at least seven of its major river basins (Speed 2010b, p. 211).

Adaptive Management

Adaptive management is an important way of responding to unexpected changes and coping with management surprises. One of the key uncertainties in surface water management is climate variability, especially unexpected and prolonged periods of below-average inflows.

All water markets, to some extent, have some elements of adaptive management. Indeed, water markets themselves are an instrument that can facilitate adaptive responses to change, such as drought, by allowing high-value uses to access water that would otherwise have been denied to them. The challenge is to ensure water markets and water planning can flexibly respond and sustain the desired public good benefits of water, such as for environmental flows. In Australia, water resource plans disproportionately favor water diversions that, typically, decline by a lesser amount than inflows in dry periods (CSIRO 2008, p. 43). As a result, in extended droughts, environmental flows can become negligible and this can generate widespread environmental degradation (The Senate Standing Committee on Rural and Regional Affairs and Transport 2008; Wentworth Group of Concerned Scientists 2010). A Basin Plan for the Murray-Darling Basin, due for implementation in 2011, will attempt to correct this fundamental failing in water planning. South Africa has also recognized the importance of adaptively managing its water resources and ecological reserves of water are being determined to meet environmental needs (e.g. Pollard, Toit and Skukuza 2009, p. 17).

In the US West there is capacity for adaptive management under state and federal environmental legislation. The absence of cost-benefit analysis and reliance upon judicial injunctions under federal endangered species and water quality legislation, however, can result in protracted legal disputes. Consequently, there is potential for greater reliance upon water markets where rights holders are compensated for environmental diversions. In the case of Chile, adaptive management is in the form of proportional allocation adjustments across all water rights in response to variability of inflows. China’s water adaptive water planning is presently in a state such that “…current approaches to defining environmental flows do not adequately account for complex relationships between flow regimes and ecosystems” (Liu and Speed 2010, p. 17).

Water Quality Considerations

Water quality is related to flows and how water is diverted and used. In all water markets some consideration is given to water quality. In the Murray-Darling Basin of Australia there are some restrictions on trade to avoid worsening salinity and the Basin Plan due for implementation in 2011 will include a water quality and salinity management plan to safeguard water quality (Murray-Darling Basin Authority 2009, p. 14). In the US, water quality is regulated by state and federal legislation. Water trades can be restricted by quality concerns. This has been the case, for example, in the Sacramento Delta where rising salinity levels contribute to reduced exports of water through the State Water Project.

In Chile, China and South Africa there is evidence of major water quality problems, at least in some rivers. In the case of Chile, the most developed water market is in the Limarí Valley and this region does not appear to have major water quality problems, but this may be more by chance than good water management (Hearne 1998, p. 145). In South Africa, the most damaging water quality issue is acid mine drainage that comes from both active and abandoned mines. Despite the fact that these problems have existed for many decades, they remain a major concern in key catchments. China has a daunting challenge to mitigate severe water quality problems, and although it is taking steps to resolve water pollution, enforcement remains weak and the problems are “…grave and deteriorating” (Lee 2006, p. 7).

Basin and Catchment-level Water Planning

Interlinked and compatible Basin and catchment water planning is necessary for integrated catchment management to address downstream externalities. In Australia, there will be a comprehensive Basin Plan for the Murray-Darling Basin in 2011 that will specify environmental water requirements and sustainable diversions for each catchment (Murray-Darling Basin Authority 2009, p. 19). However, the actual catchment water resource plans will be developed by state governments and these do not need to be consistent with the Basin Plan until current plans expire, which in some cases does not occur until 2019.

Chile has a decentralized planning system and there is a tightly circumscribed role for the relevant Water Ministry. The absence of river basin institutions also prevents any administrative engagement with water planning, including in the Limarí Valley (Bauer 2004, pp. 96-7). Instead, irrigation associations and officials in the Irrigation Bureau effectively manage Limarí's water supply on a year-to-year basis (Zegarra 2008, p. 41). In the US there is partial basin-wide water management regarding environmental flows. Basins often cross multiple political jurisdictions so that differing regulations and agencies are involved, although federal quality regulations generally apply. The 18 interstate water basin compacts have had limited coordinated environmental roles, and in California the Integrated Regional Water Management Plan Program (IRWMP) has been expanded to promote water planning outside traditional political boundaries.

South Africa's *National Water Act 1998* provides for catchment-level planning for environmental and human needs through reserves. However, slow progress in creating catchment management authorities has meant that water planning remains in its infancy in most catchments. China's seven major river basins all have comprehensive water plans, but these focus solely on allocation and utilization and do not necessarily incorporate more holistic objectives such as water quality, environmental protection and human needs (Zhou 2006, p. 6).

Water Markets: An Overview

The five markets assessed under the integrated framework is by no means an exhaustive list. Informal markets exist in many other countries such as India and Pakistan, as well as more formal water markets, such as in Mexico (Easter, Rosegrant and Diner 1998). Benchmarking across water markets would assist informed policy makers to make judgments about how they can be further developed to achieve particular goals. We contend that our integrated framework shows the important linkages between water market development, institutional constraints, and management goals. Understanding these connections is crucial to good water governance and, thus, recommendations about what criteria should be further developed is contingent on the espoused goals, institutions and capacity where water markets are located. The integrated framework, thus, should be viewed as a road map or guide that offers multiple routes and options about how to move from points A to B, or points A to C, depending on what the ‘driver’ wants and what ‘vehicle’ is available, rather than a single pathway to a unique destination.

In closing, we provide ten key insights from the application of the integrated framework to five water markets. First, institutions matter. Thus, what may work in one water market may not necessarily be as successful in another with different institutions. This also implies an important role for water regulators or governments to support water markets to ensure that they are delivering the desired societal benefits. Second, some water markets have developed and evolved for purposes other than economic efficiency. Trade-offs between equity and efficiency exist in water market design and operation, even if these trade-offs are not always as transparent as they are in South Africa. Third, Australia shows that markets can be adapted to account for environmental sustainability without necessarily compromising economic efficiency. Fourth, markets can successfully work in small catchments, such as Chile’s Limarí Valley, as well as in large basins, such as the Murray-Darling in Australia. Fifth, water markets can generate substantial gains for buyers and sellers that would not otherwise occur, and these gains increase as water availability declines. Sixth, there is a need for flexibility in water markets so that they can change as the benefits of water use and *in situ* use change over time, as has happened in the US West and Australia. Seventh, there must be a close connection between water markets and water planning to provide surety to holders of water rights while also sustaining the public good aspects of water. Eighth, history matters. For instance, the path dependence of the US with its appropriative rights is likely to be different to that of Australia that has statutory rights. Ninth, differences in regulatory capacity (human and financial) to support water markets help to explain some of the variation in the performance of water markets, such as between China and the US. Tenth, performance must match goals. Thus, if equity is the primary goal, such as in South Africa, then water markets should be judged on this priority rather than objectives that may dominate in other jurisdictions, such as economic efficiency.

References

Anderson, Terry L. and Ronald N. Johnson. 1986. The problem of instream flows. *Economic Inquiry*. 24(4): 535-53.

Bauer, Carl J. 2004. *Siren song: Chilean water law as a model for international reform*. Washington D.C.: Resources for the Future.

Bauer, Carl J. 1997. Bringing water markets down to earth: The political economy of water rights in Chile, 1976-95, *World Development*. 25(5): 639-656.

Brehm, Monica Rios, and Jorge Quiroz. 1995. The market for water rights in Chile: Major issues, *World Bank technical paper no.285*. Washington D.C.: The World Bank.

Brewer, Jedidiah, and Gary D. Libecap. 2009. Property rights and the public trust doctrine in environmental protection and natural resource conservation. *The Australian Journal of Agricultural and Resource Economics*. 53: 1–17.

Brewer, Jedidiah, Robert Glennon, Alan Ker, and Gary D. Libecap. 2008. Water markets in the west: prices, trading, and contractual flows. *Economic Inquiry*. 46(2): 91-112.

Brewer, Jedidiah, Michael A. Fleishman, Robert Glennon, Alan Ker, and Gary Libecap. 2008. Law and the new institutional economics: water markets and legal change in California. *Washington University Journal of Law and Policy*. 26: 183-214.

Briscoe, John, Pablo Anguita Salas and Humberto Peña T. 1998. Managing water as an economic resource: Reflections on the Chilean experience, *Environment Department Paper no. 62*, Environmental Economics Series. Washington D.C.: The World Bank.

Connell, Daniel, and R. Quentin Grafton. 2008. Planning for water security in the Murray-Darling Basin. *Public Policy*. 3(1): 67-86.

Crase, Lin, and Suzanne O'Keefe. 2009. The paradox of national water savings: A critique of 'Water for the Future'. *Agenda*. 16(1): 45-60.

CSIRO. 2008. *Water availability in the Murray-Darling Basin*. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. Canberra, CSIRO.

Dinar, Ariel, and R. Maria Saleth. 2005. Can water institutions be cured? A water institutions health index. *Water Science and Technology: Water Supply*. 5(6): 17-40.

Easter, K. William, Mark W. Rosegrant, and Ariel Dinar. 1999. Formal and informal markets for water: Institutions, performance and constraints. *The World Bank Research Observer*. 14(1): 99-116.

Easter, K. William, Mark W. Rosegrant, and Ariel Dinar (eds). 1998. *Markets for water: potential and performance*. Boston: Kluwer Academic Publishers.

Eden, Susanna, Robert Glennon, Alan Ker, Gary Libecap, Sharon Megdal, and Taylor Shipman, 2008. Agricultural water to municipal use: the legal and institutional context for voluntary transactions in Arizona. *The Water Report*. 58: 9-20.

Falkenmark, Malin. 1999. Forward to the future: A conceptual framework for water dependence. *Ambio*. 28(4): 356-361.

Farolfi, S., and S. Perret. 2002. Inter-sectoral competition for water allocation in rural South Africa: Analysing a case study through a standard environmental economics approach, *Working paper 2002-23*, Department of Agricultural Economics, University of Pretoria.

Getches, David H. 1997. *Water law in a nut shell*, St. Paul: West Publishing Co.

Gould, George. A. 1995. Recent developments in the transfer of water rights. In *Water law: Trends, policies, and practice*, ed. Kathleen Marion Carr and James D. Crammond, 93–103, Chicago: American Bar Association.

Ghassemi, Fereidounm, and Ian White. 2007. *Inter-basin water transfer: Case studies from Australia, United States, Canada, China, and India.* Cambridge, England: Cambridge University Press.

Gillet, C.G., W.L. Nieuwoudt and G.R. Backeberg. 2005. Water markets in the Lower Orange River catchment of South Africa, *Agrekon*. 44(3): 363-382.

Glennon, Robert Jerome. 2009. *Unquenchable: America's water crisis and what to do about it*, Washington D.C.: Island Press.

Grafton, R. Quentin, and Karen Hussey. 2007. Buying back the Living Murray: At what price? *Australasian Journal of Environmental Management*. 14: 74-81.

Grafton, R. Quentin, Clay Landry, Gary D. Libecap, and Robert J. O'Brien. 2010. Water markets: Australia's Murray-Darling Basin and the US Southwest. *NBER Working Paper*. w15791, Cambridge: Ma.

Haddad, Brent M. 2000. *Rivers of gold: designing markets to allocate water in California*. Washington D.C.: Island Press.

Hanak, Ellen. 2003. *Who should be allowed to sell water in California? Third-party issues and the water market*. San Francisco: Public Policy Institute of California.

Hadjigeorgalis, Ereney, and Jay Lillywhite. 2004. The impact of institutional constraints on the Limari River Valley water market, *Water Resources Research*. 40, W05501, doi:10.1029/2003WR002701.

Hearne, Robert R. 1998. Institutional and organisational arrangements for water markets in Chile. In *Markets for water: Potential and performance*, ed. K. William Easter, Mark W. Rosegrant and Ariel Dinar, 181-158. Massachusetts: Kluwer Academic Publishers.

Hollinshead, Sarah P. 2008. Water is not liquid: Securitization, transaction costs, and California's water market. *Columbia Journal of Environmental Law*. 33(2): 323-368.

Howe, Charles W., Dennis R. Schurmeier, and W. Douglas Shaw. 1986. Innovative approaches to water allocation: The potential for water markets. *Water resources Research*. 22(4): 439-445.

Howitt, Richard. E. 1994. Effects of water marketing on the farm economy. In *Sharing Scarcity: Gainers and Losers in Water Marketing*, ed. H. O. Carter, H. J. Vaux Jr, and A. F. Scheuring. Davis, 97–132. Davis, CA: Agricultural Issues Center,

Johnson, Ronald N., Micha Gisser, and Michael Werner. 1981. The definition of a surface water right and transferability. *Journal of Law and Economics*. 24 (2): 273-88.

Kanazawa, Mark T. 1998. Efficiency in western water law: The development of the California doctrine, 1850-1911. *Journal of Legal Studies*. 27(1): 159-185.

Khan, Haider, and Yibei Liu. 2008. Ecological economics of water in China: Towards a strategy for sustainable development. *MPRA paper no. 7705*, Munich Personal RePEc Archive. Published March 2008.

Landry, Clay. 2010. *Water Transfer Dataset.* WestWater Research, LLC, Boise, Idaho.

Lee, S. 2006. China's water policy challenges. *China Policy Institute discussion paper 13*, University of Nottingham.

Lenton, Roberto, and Mike Muller. 2009. Introduction. In *Integrated water resources management in practice: Better water management for development*, eds. Roberto Lenton, and Mike Muller. Earthscan: London.

Liao, Yongsong, Zhanyi Gao, Ziyun Bao, Qingwen Huang, Guangzhi Feng, Di Xu, Jiabin Cai, Huijing Han, and Weifeng Wu. 2008. China's water pricing reforms for irrigation: Effectiveness and impact. *CA Discussion Paper 6*. Comprehensive Assessment of water management in agriculture. Colombo: International Water Management Institute.

Libecap, Gary D. 2007. *Owens valley revisited: a reassessment of the west's first great water transfer.* Palo Alto: Stanford University Press.

Liu, Bin, and Robert Speed. 2010. Water resources management in the People's Republic of China. In *Water resources management in the People's Republic of China*, ed. Xeutao Sun, Robert Speed, and Dajun Shen. New York: Routledge.

Livingston, Marie Leigh 1993. Normative and positive aspects of institutional economics: The implications for water policy. *Water Resources Research* 29(4): 815-821.

Ludwig, Fulco and Marcus Moench. 2009. The impacts of climate change on water. In *Climate change adaptation in the water sector*, eds. Fulco Ludwig, Pavel Kabat, Henk van Schaik, and Michael van der Valk, 35-50. London: Earthscan Publishing.

Malzbender, Daniel, Jaqui Goldin, Anthony Turton, and Anton Earle. 2005. Traditional water governance and South Africa's National Water Act: Tension or cooperation? Paper presented at the international workshop African water laws: Plural legislative frameworks for rural water management in Africa, Johannesburg, South Africa, January, 26-28.

Muller, C. 2009. Attempting to do it all: How a new South Africa has harnessed water to address its development challenges, In *Integrated water resources management in* *practice: Better water management for development*, eds. Roberto Lenton, and Mike Muller. London: Earthscan: London.

Murray-Darling Basin Authority. 2009. The Basin Plan: A concept statement. MDBA Publication no. 02/09, June.

National Water Commission. 2009a. *Australian water reform 2009: Second biennial assessment of progress in implementation of the National Water Initiative*. Canberra: National Water Commission.

National Water Commission. 2009b. *Australian water markets report 2008-09*. Canberra: National Water Commission.

Neuman, Janet C. 2004. The good, the bad, and the ugly: The first ten years of the Oregon water trust. *Nebraska Law Review*. 83: 432-84.

Nieuwoudt, W. L., C. G. Gillet, and G. R. Backeberg. 2005. Water marketing in the Crocodile River, South Africa. *Agrekon.* 44(3): 383-401.

Nieuwoudt, W. L. and R. M. Armitage. 2004. Water market transfers in South Africa: Two case studies. *Water Resources Research*. 40, W09S05, doi:10.1029/2003WR002840.

Nieuwoudt, W. L. 2000. Water market institutions: Lessons from Colorado. *Agrekon.* 39(1): 58-67.

Palaniappan, Meena, and Gleick, Peter H. 2009. Peak water, In *The World's Water 2008-2009 The Biennial Report on Freshwater Resources*, ed. Peter H. Gleick, Heather Cooley, Michael Cohen, Mari Morikawa, Jason Morrison, and Meena Palaniappan, 1-16. Washington D.C.: Island Press.

Peterson, Deborah, Gavin Dwyer, David Appels, and Jane M. Fry. 2004. *Modelling water trade in the southern Murray-Darling Basin*. Productivity Commission Staff Working Paper. Melbourne, Productivity Commission.

Pollard, Sharon R., Derick du Toit, and S. Mallory Skukuza. 2009. Drawing environmental water allocations into the world of realpolitik: Emerging experiences on achieving compliance with policy in the Lowveld rivers, South Africa. Paper presented at the International Conference on Implementing Environmental Water Allocations, Port Elizabeth, February 23-26.

Postel, Sandra L., Gretchen C. Daily, and Paul R. Ehrlich. 1996. Human appropriation of renewable fresh water. *Science*, 271: 785-788.

Pott, A., K. Versfeld, M. van Rooyen and A. Muir. 2009. *A scoping exercise to investigate the potential need for, and nature of, water trading in South Africa*. WRC Report No. KV 222/09. South African Water Research Commission.

Productivity Commission. 2010. *Market mechanisms for recovering water in the Murray-Darling Basin*. Melbourne, Productivity Commission.

Richards, Elizabeth H. 2008. *Over-allocation and the doctrine of prior appropriation; water rights settlement agreements in New Mexico*. PhD Dissertation, Interdisciplinary Graduate Program in Environment and Resources, Stanford University

Rosegrant, Mark, and Hans P. Binswanger. 1994. Markets in tradable water rights: Potential for efficiency gains in developing country water resource allocation. *World Development*. 22: 1613-1625.

Saleth, R. Maria, and Ariel Dinar. 2000. Institutional changes in global water sector: Trends, patterns, and implications. *Water Policy*, 2(3): 175-199.

Saleth, R. Maria, and Ariel Dinar. 2004. *The institutional economics of water: A cross country analysis of institutions and performance.* Cheltenham: Edward Elgar Publishing.

Sax, Joseph. 1970. The public trust doctrine in natural resource law: effective judicial Intervention. *Michigan Law Review*. 68: 471–566.

Scarborough, Brandon. 2010. *Environmental water markets: restoring streams through trade.* PERC Policy Series No. 46. Bozeman, MT: PERC.

Shen, D. and R. Speed. 2010. Water resources allocation in the People's Republic of China. In *Water resources management in the People's Republic of China*, ed. Xuetao Sun, Robert Speed and Dajun Shen. New York: Routledge.

Shiklomanov, I.A.2003. World water use and water availability, In *World Water Resources at the Beginning of the 21st Century*, eds. I.A. Shiklomanov, and John C. Rodda, 369-389. Cambridge, England: Cambridge University Press.

Speed, R. 2010a. A comparison of water rights systems in China and Australia. In *Water resources management in the People's Republic of China*, ed. Xuetao Sun, Robert Speed and Dajun Shen. New York: Routledge.

Speed, R. 2010b. Transferring and trading water rights in the People's Republic of China. In *Water resources management in the People's Republic of China*, ed. Xuetao Sun, Robert Speed and Dajun Shen. New York: Routledge.

Sullivan, Caroline. 2002. Calculating a water poverty index. *World Development*. 30(7): 1195-1210.

Sun, Xuetao. 2010. Introduction: The development of a water rights system in China. In *Water resources management in the People's Republic of China*, ed. Xuetao Sun, Robert Speed and Dajun Shen. New York: Routledge.

The Senate Standing Committee on Rural and Regional Affairs and Transport. 2008, *Water management in the Coorong and the Lower Lakes.* Canberra: Parliament of Australia.

Thompson, Barton H. 1993. Institutional perspectives on water policy and markets. *California Law Review*. 81: 673-764.

Trelease, Frank J. 1955. Preferences to the use of utility. *Rocky Mountain Law Review*. 27: 133-60.

Turton, Anthony R., Marian J. Patrick, and Jeanette Rascher. 2008. Editorial: Setting the scene – hydropolitics and the development of the South African economy. *Water Resources Development*. 24(3): 323-327.

Water Research Commission. 2009. Experts united to save abused river from extinction. *The Water Wheel*. 8(1): 14-17.

Wentworth Group of Concerned Scientists in association with R.Q. Grafton, I. Kowalick, C. Miller, T. Stubbs, F. Verity and K. Walker. 2010, *Sustainable diversions in the Murray-Darling Basin: An analysis of the options for achieving a sustainable diversion limit in the Murray-Darling Basin.* Melbourne: Wentworth Group of Concerned Scientists.

World Bank. 2002. *China: Country water resources assistance strategy*. The World Bank East Asia and Pacific Region. Washington D.C.: The World Bank.

Xie, Jian. 2008. *Addressing China's water scarcity: Recommendations for selected water resource management issues*. Washington D.C.: The World Bank.

Zegarra, Eduardo. 2008. *Water markets and coordination failures: A case study from Chile*. Saarbrucken: VDM Verlag Dr. Muller Aktiengesellscharft & Co. KG.

Zhou, G. 2006. *Institutional arrangements for river basin management: A case study comparison of the United States and China.* World Bank Policy Note 37747, China Water Analytical and Advisory Assistance Program. Washington D.C.: IBRD, The World Bank.

Table 1. Institutional Underpinnings

	Recognition of public interest	Administrative capacity	Well developed horizontal linkages	Well developed vertical linkages	Legal/administrative clarity	Conflict resolution	Adaptive management of institutions	Registration/titling
Australia	💧💧	💧💧	💧💧💧	💧	💧💧💧	💧💧	💧💧	💧💧
US West	💧💧	💧💧	💧	💧	💧	💧	💧💧💧	💧
Chile	💧	X	💧💧	💧💧	💧💧	💧	X	💧
South Africa	💧💧	💧	💧💧	(pending)	X	I	(pending)	(pending)
China	💧	X	X	X	X	X	💧	I

💧💧💧	Nearly or fully satisfied
💧💧	Mostly satisfied, some further development required
💧	Partly satisfied, substantial further development required
X	Not satisfied/Missing/Not operational
I	Inadequate info

Table 2. Economic Efficiency

	Size of market (permanent/ temporary)	Gains from trade (US$ million)	Nature of water products	Quality of title	Breadth of market	Stability of price formation	Market pricing information	Storage (ratio of average use)
Australia	12.5/20.1 %	495	💧💧💧	💧💧💧	💧💧	💧💧💧	💧💧	2.0
US West	I	406	💧💧💧	💧	💧	💧	💧	2.3 (Colorado)
Chile	15/30 %	22.1	💧💧💧	💧💧	💧💧	💧💧	💧	3.3
South Africa	I	I	💧	💧	💧	💧💧	💧	I
China	I	I	X	X	💧	💧	N/A	I

💧💧💧	Nearly or fully satisfied
💧💧	Mostly satisfied, some further development required
💧	Partly satisfied, substantial further development required
X	Not satisfied/Missing/Not operational
I	Inadequate info

Table 3. Equity

	Beneficial use in extractions	Basic human needs	Controls on market power	Third-party impacts	Initial allocation
Australia	💧💧💧	💧💧💧	💧💧	💧	💧💧
US	💧💧💧	💧💧💧	💧💧	💧	💧💧
Chile	💧	💧💧💧	💧	💧	💧
South Africa	💧💧	💧💧	I	💧💧	(pending)
China	X	💧	N/A	X	N/A

💧💧💧	Nearly or fully satisfied
💧💧	Mostly satisfied, some further development required
💧	Partly satisfied, substantial further development required
X	Not satisfied/Missing/Not operational
I	Inadequate info

Table 4. Environmental Sustainability

	Adequate scientific data	Adequate provisions for environmental flows	Adaptive management of environmental needs	Water quality considerations in water planning	Basin and catchment-level water planning
Australia	💧	(pending)	(pending)	(pending)	(pending)
US	💧💧	💧	💧	💧💧	💧
Chile	💧	💧	💧	💧	💧
South Africa	💧	(pending)	I	I	I
China	X	💧	X	💧	X

💧💧💧	Nearly or fully satisfied
💧💧	Mostly satisfied, some further development required
💧	Partly satisfied, substantial further development required
X	Not satisfied/Missing/Not operational
I	Inadequate info